Shallow Lake Ecology

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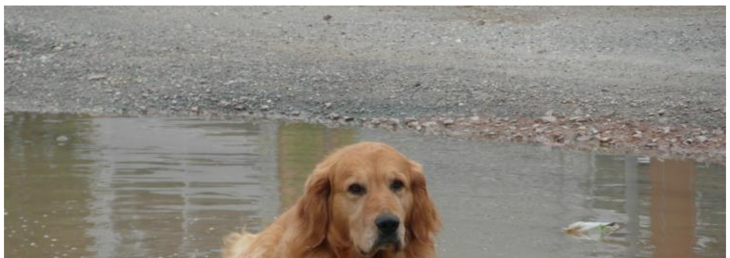
Shallow Lake Limnology (how shallow lakes are unique and valuable)

- **First off, what's a shallow lake?**



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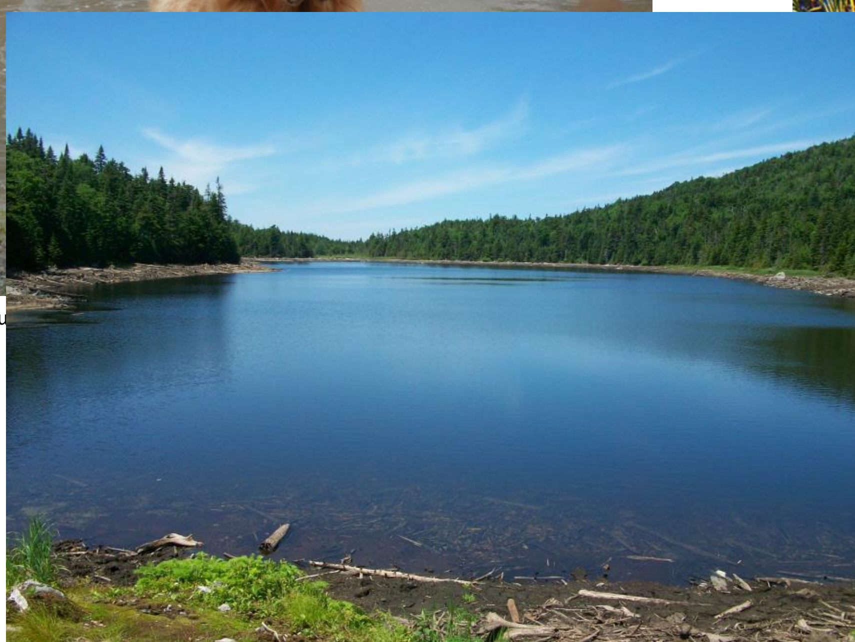


https://talltimberlodge.files.wordpress.com/2010/06/boundary-pond-1.jpg

http://cdn0.wideopenspaces.com/wp-content/uploads/2017/12/Sanford-5.jpg

Shallow Lake Definition

https://en.wikipedia.org/wiki/Pond#/media/File:Staw_naturalny.JPG

- **Often considered to be a lake whose euphotic zone can potentially reach the full sediment area**
- **Other definitions may include freezing to the bottom (in northern lakes), or full macrophyte coverage.**

Lake Formation and Life History

Tectonic Lakes

Glacial Lakes

The Pros and Cons of Being Shallow

PROS

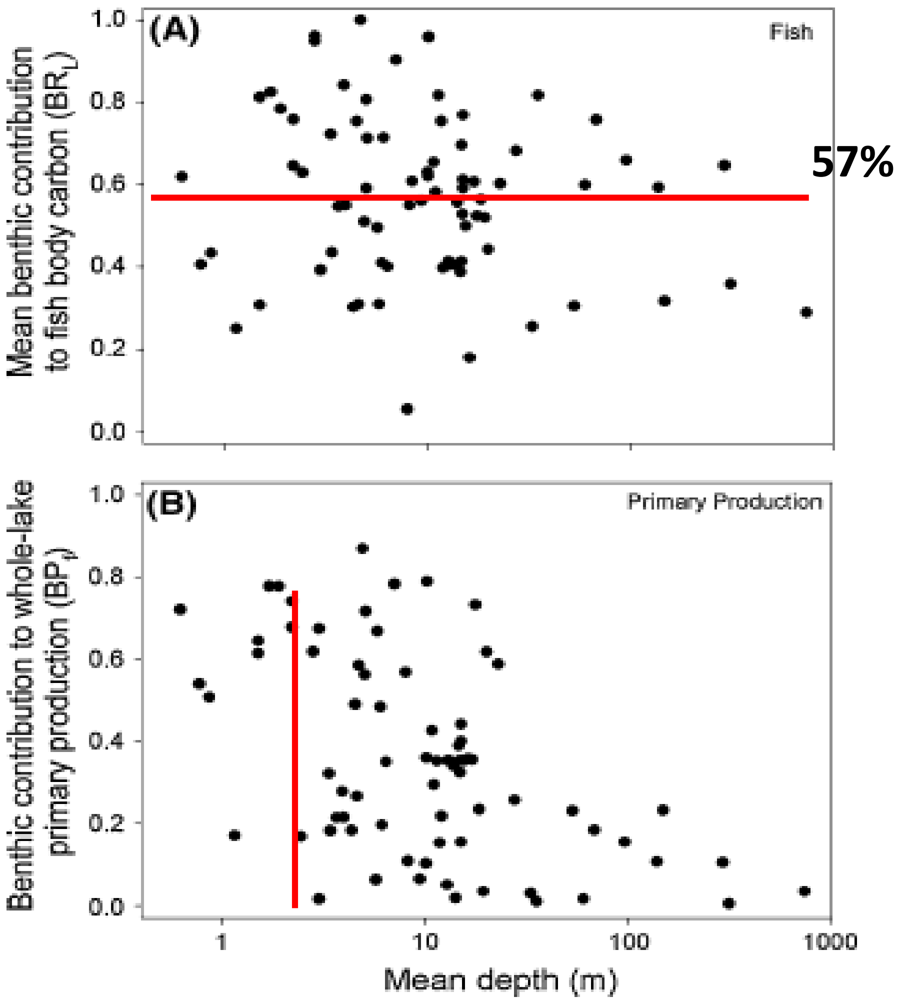
- Greater focusing of imported carbon and nutrients (lower dilution, CA:LA ratio)
- Potential maximized usage of primary productive space (light to the bottom, allowing for macrophyte beds and benthic algae)
- Greater productive potential from without and within

CONS

- Higher risk of freezing to the bottom
- Greater susceptibility to mixing (pro or con, depending on location, fetch, stratification, etc.)
- Greater susceptibility to regime shifts

Nutrient cycling and turbidity in shallow lake ecology

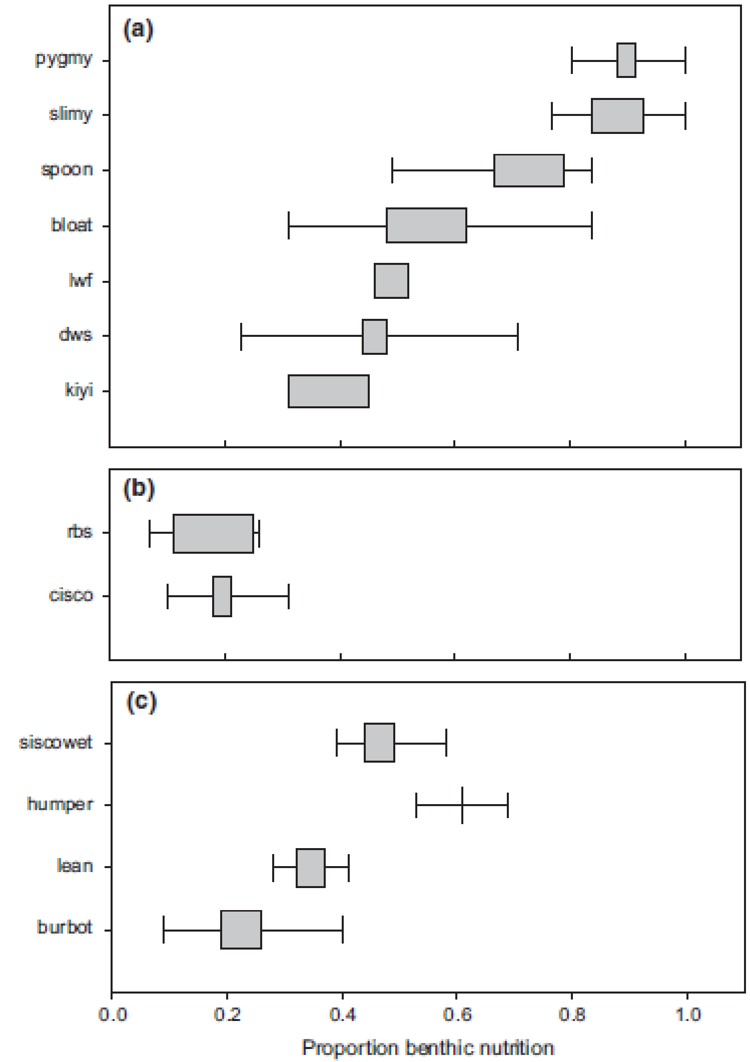
- Periphyton (benthic algae) tend to be light-limited, phytoplankton nutrient-limited
- Benthic-pelagic coupling: important in lakes, but potentially most powerful in shallow lakes
- Light access to the benthic zone is key
- The benthic zone can (most commonly) be removed from the photic zone by
  - Deepening water column
  - Increased turbidity from resuspension
  - Increased turbidity from phytoplankton production



Vander Zanden et al., 2011

Regime Shifts and the importance of benthic processes

- Benthic zone can be important in large, oligotrophic lakes, but it is harder for those to “flip” to phytoplankton dominance



Vancer Zanden et al., 2011

Regime Shifts and the importance of benthic processes

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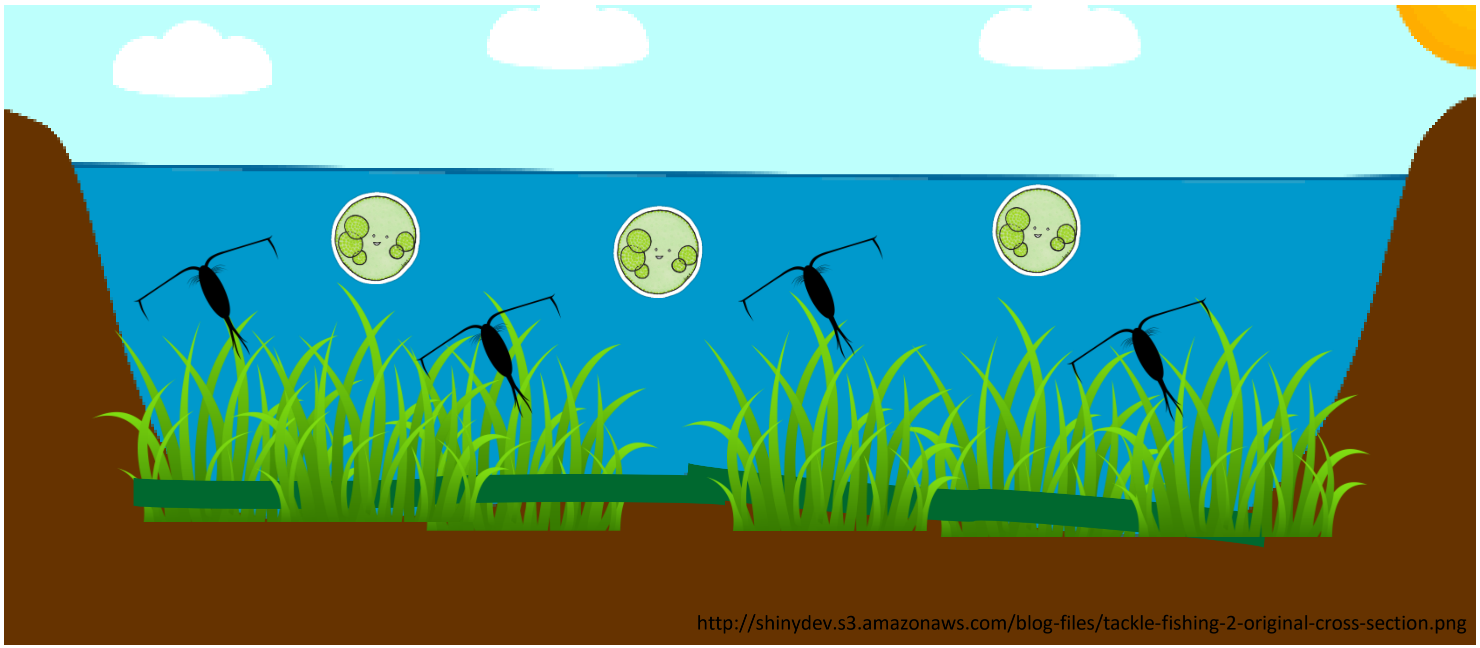

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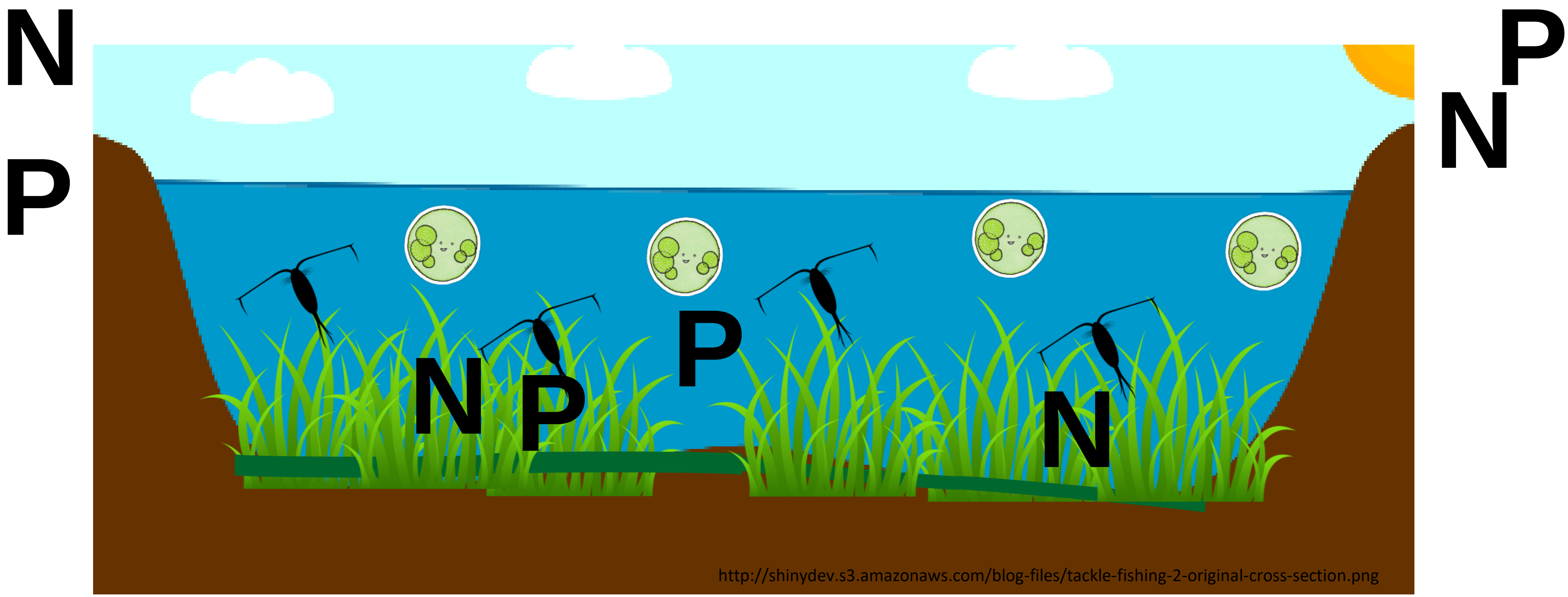
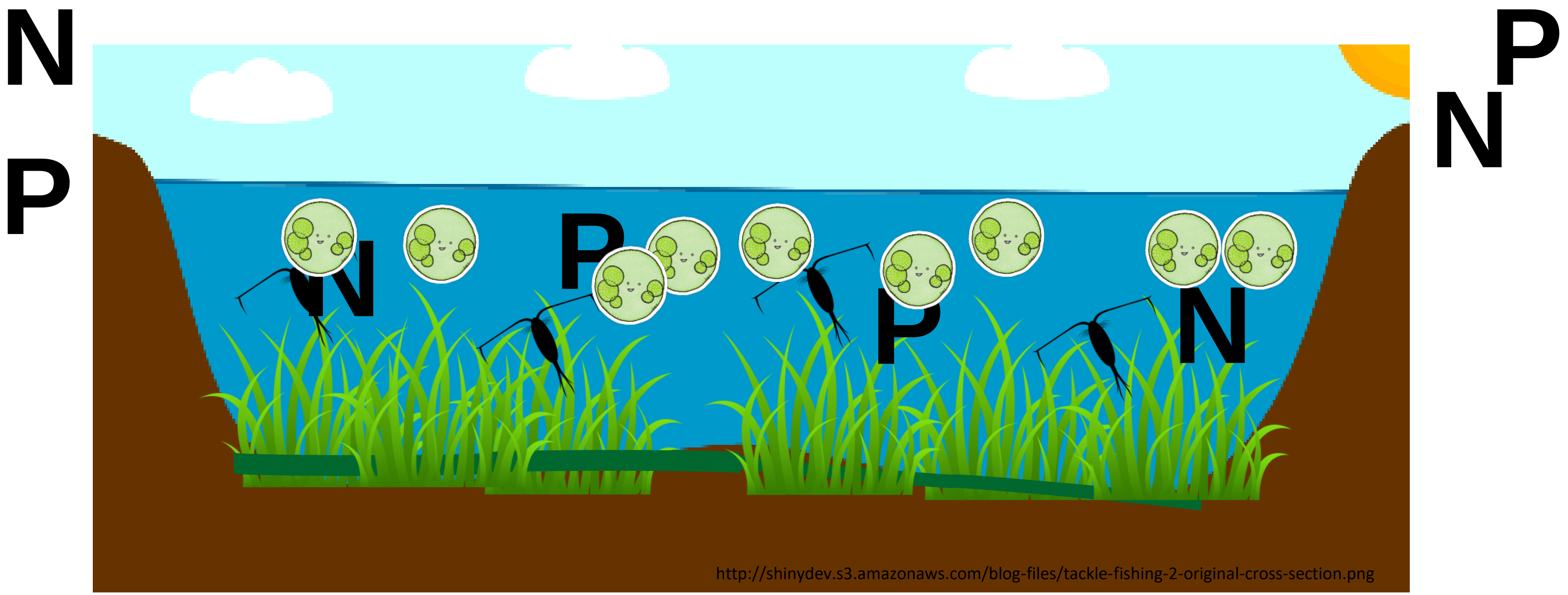
CLEAR-WATER STATE (macrophyte dominated)

Regime Shifts and the importance of benthic processes



CLEAR-WATER STATE
(macrophyte dominated)

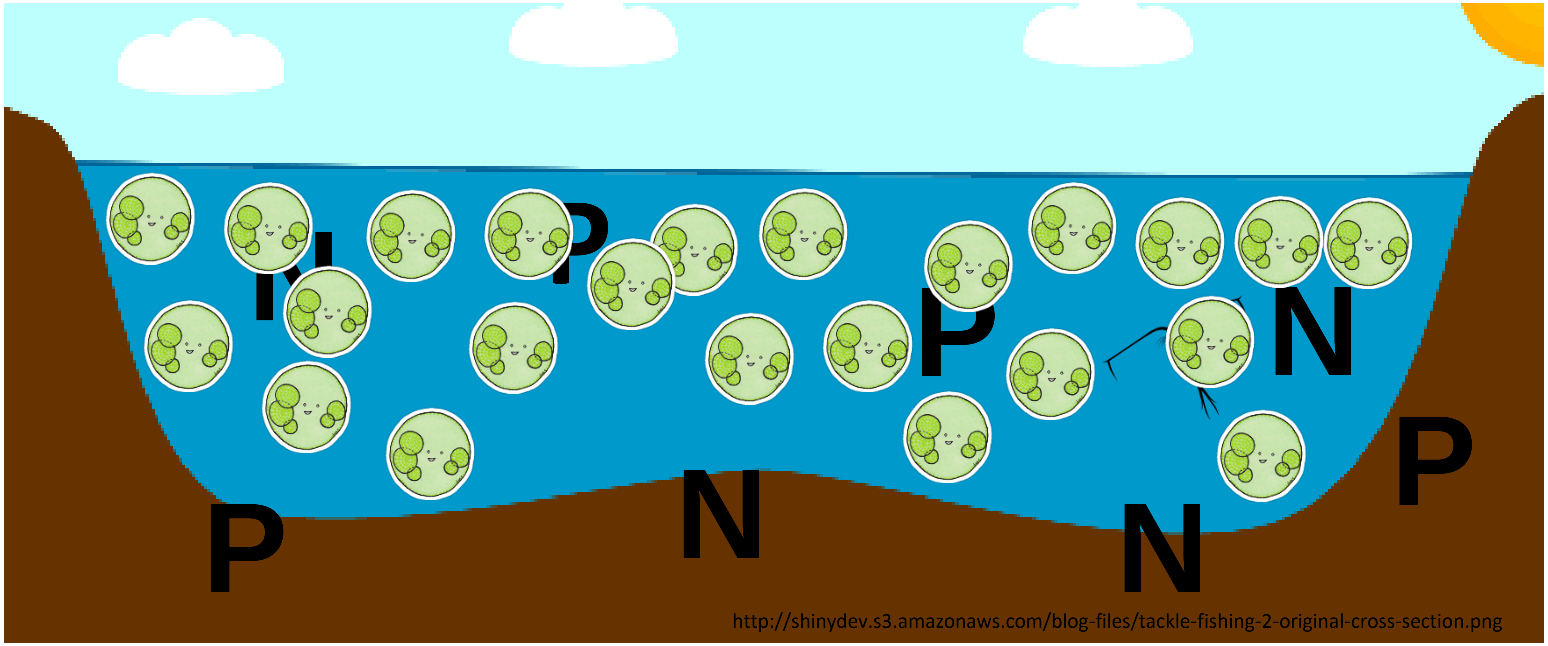
Regime Shifts and the importance of benthic processes



CLEAR WATER STATE
(macrophyte-dominated)

TURBID STATE
(phytoplankton-dominated)

Regime Shifts and the importance of benthic processes



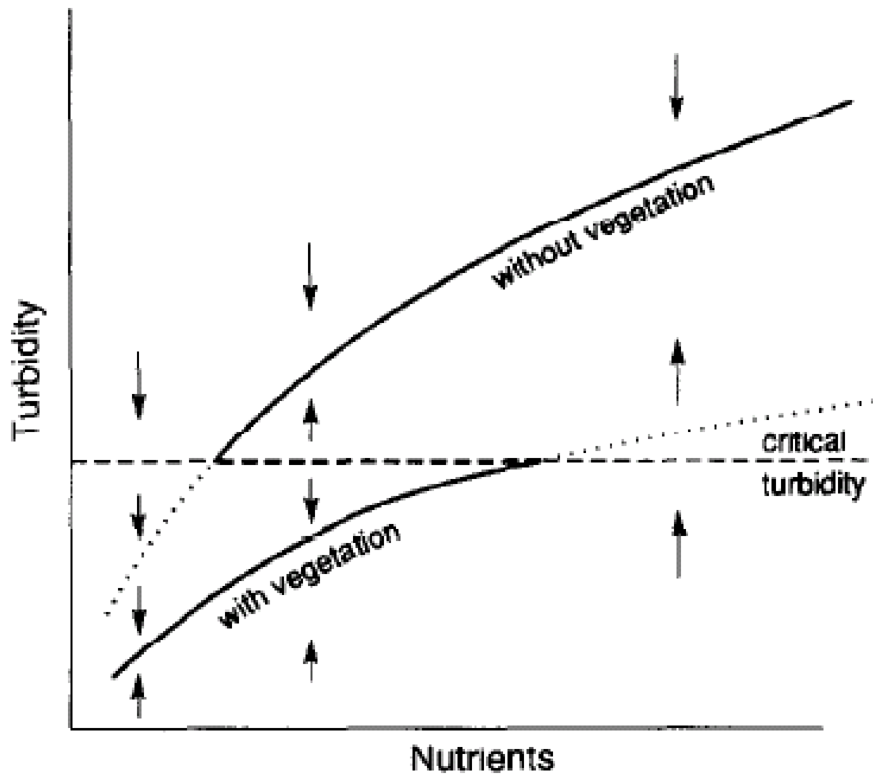
TURBID STATE (phytoplankton-dominated)

Regime Shifts and the importance of benthic processes

- **Two important points:**
- **Not all shallow lakes are eutrophic**
- **Not all eutrophic lakes are functionally equal.**

Regime Shifts and the importance of benthic processes

- What's important isn't necessarily how shallow a lake is, or even entirely how concentrated its nutrients are, but how its ecosystem is processing/cycling those nutrients
- Important to distinguish whether "eutrophic" refers to nutrient concentrations or lake condition
- Once a regime shift occurs, it can be very difficult to reverse
- Regime shifts can be precipitated by disturbances (natural or anthropogenic)



Scheffer et al., 1993

Eutrophication and Anoxia in the Context of Regime Shifts

- In extreme cases, eutrophication can lead to anoxia/hypoxia, resulting in fish kill events and internal nutrient loading
- This is typically associated with phytoplankton dynamics, though periphyton may also theoretically play a role

High nutrient (esp. phosphorus) loading

High phytoplankton production

Phytoplankton settle to hypolimnion

Phytoplankton load increases bacterial production

Sediment oxygen demand increases

Hypoxia

High nutrient (esp. phosphorus) loading

High ph

Phytoplan

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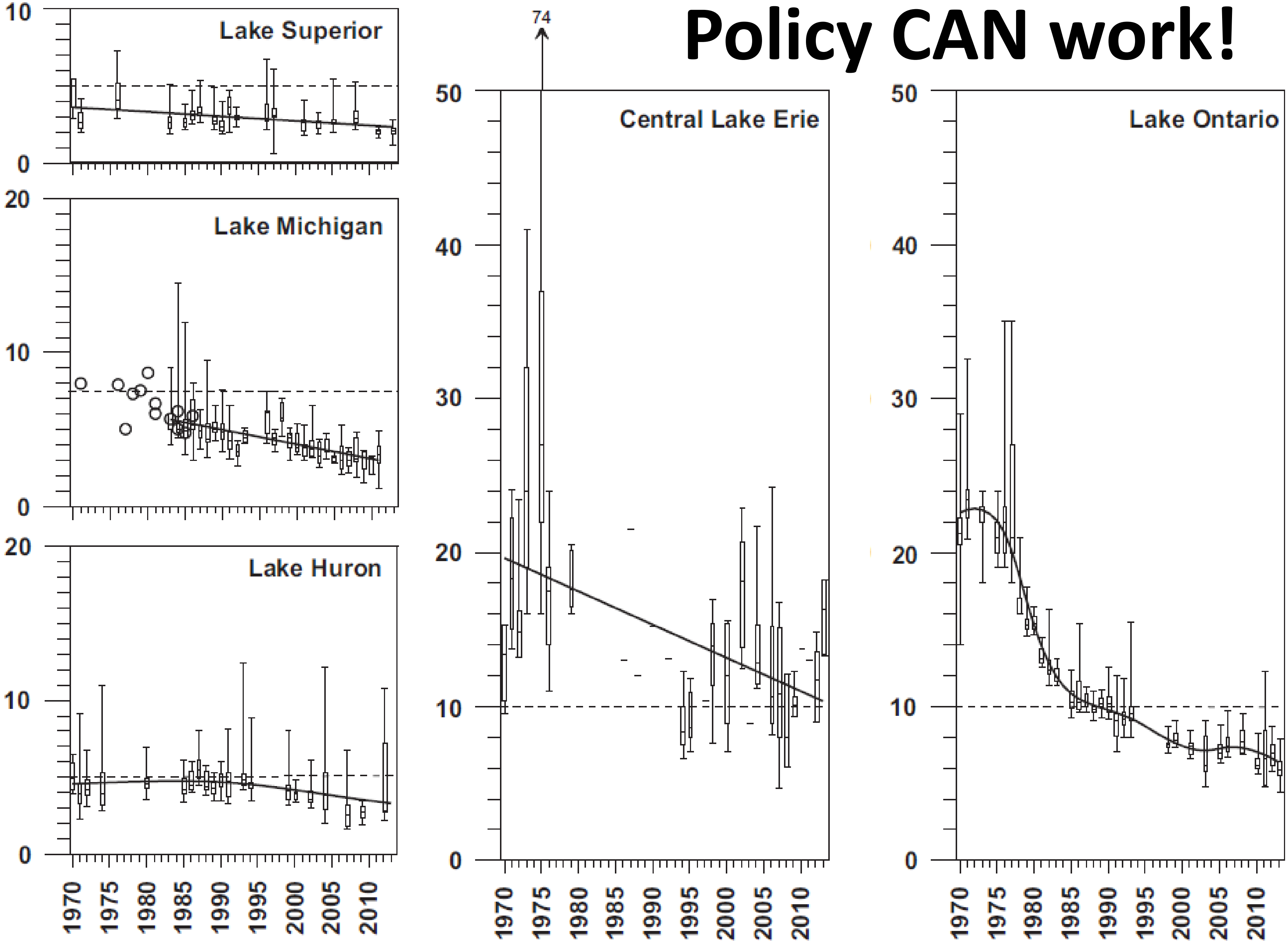
increases
ction

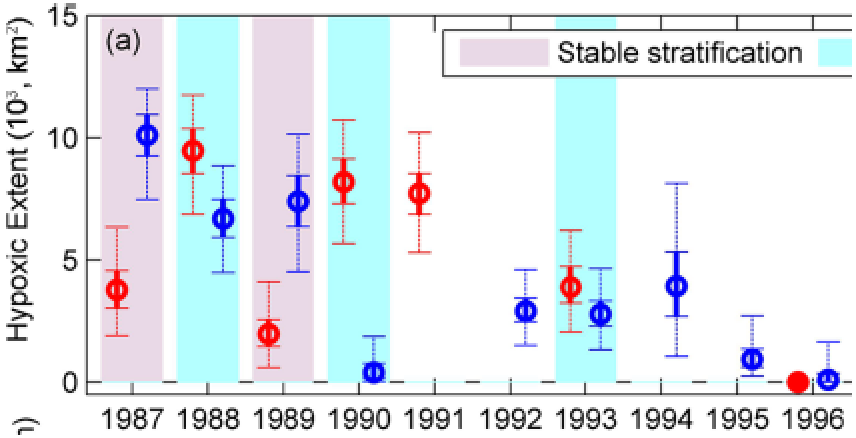
and increases

Policy CAN work!



Dove and Chapra, 2015

Recent history (hypoxic extent)

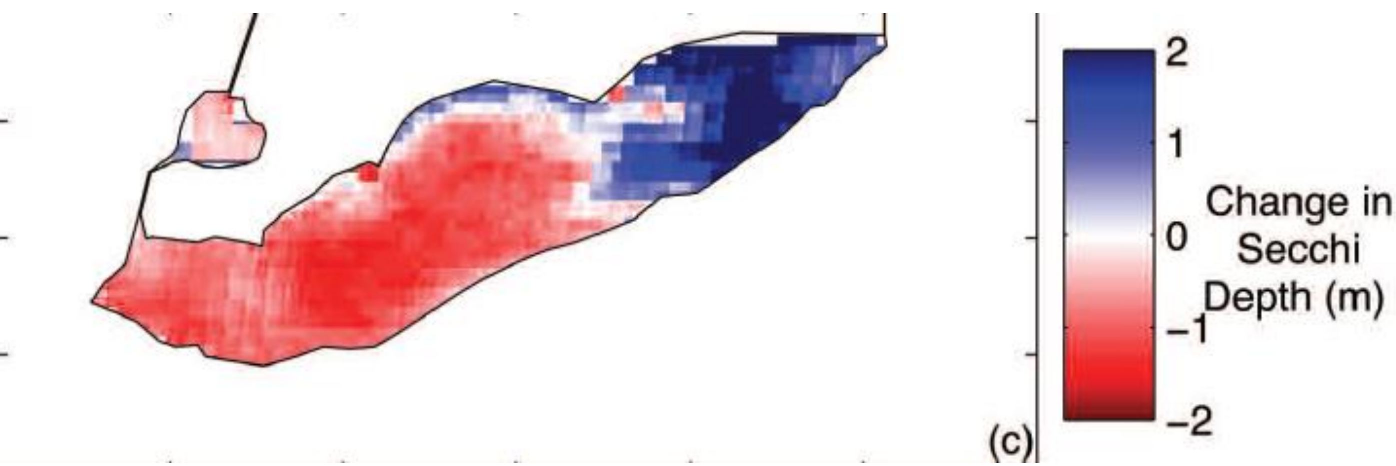


Introduction of zebra mussels,
reduction in nutrient loading

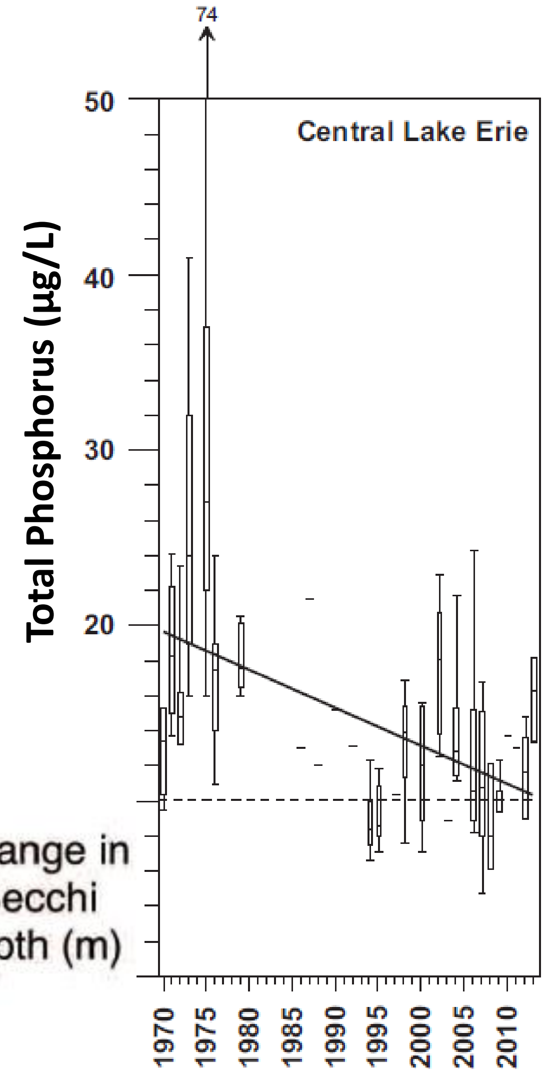
Zhou et al., 2013

Erie Hypoxia

- Phosphorus declined
- Water clarity declined
- Sediment/hypolimnetic oxygen demand declined



Binding et al., 2007



Dove and Chapra, 2015

High nutrient (esp. osphorus) loading

High phytoplar on production

Phytoplankton settle to hypolimnion

http://img3.rnkr-static.com/user_node_img/50051/1001007992/870/jnco-jeans-photo-u1.jpg

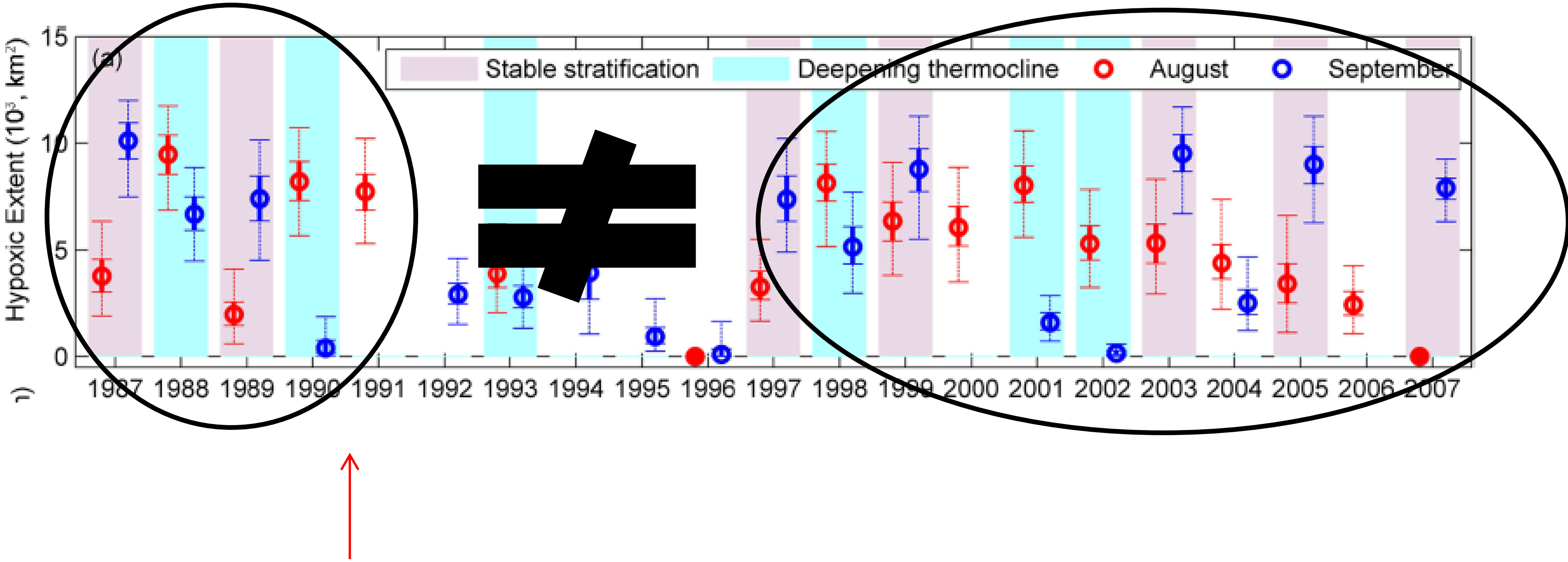
Phytoplankton load increases bacterial production

Sediment oxyger emand increases

Hypoxia ✓

Recent history (hypoxic extent)

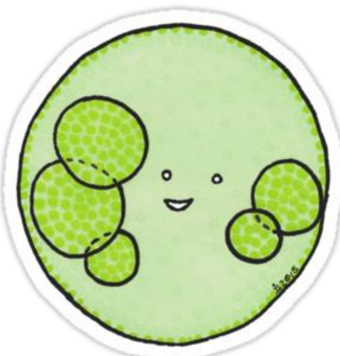
historical hypoxia **modern hypoxia**

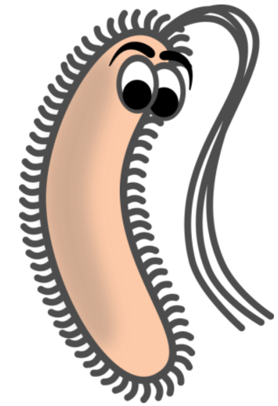


Introduction of zebra mussels, reduction in nutrient loading

Zhou et al., 2013

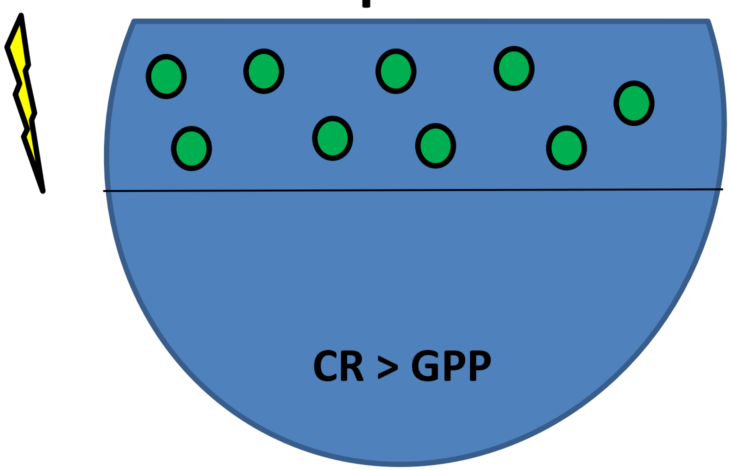
Rethinking Hypoxia

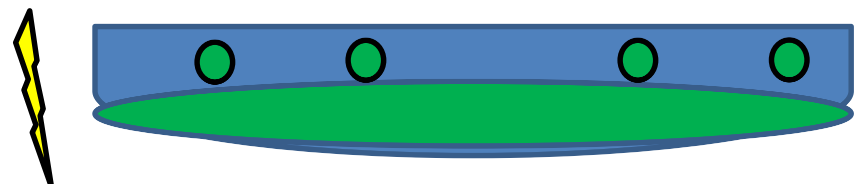




Deep waters

Shallow waters

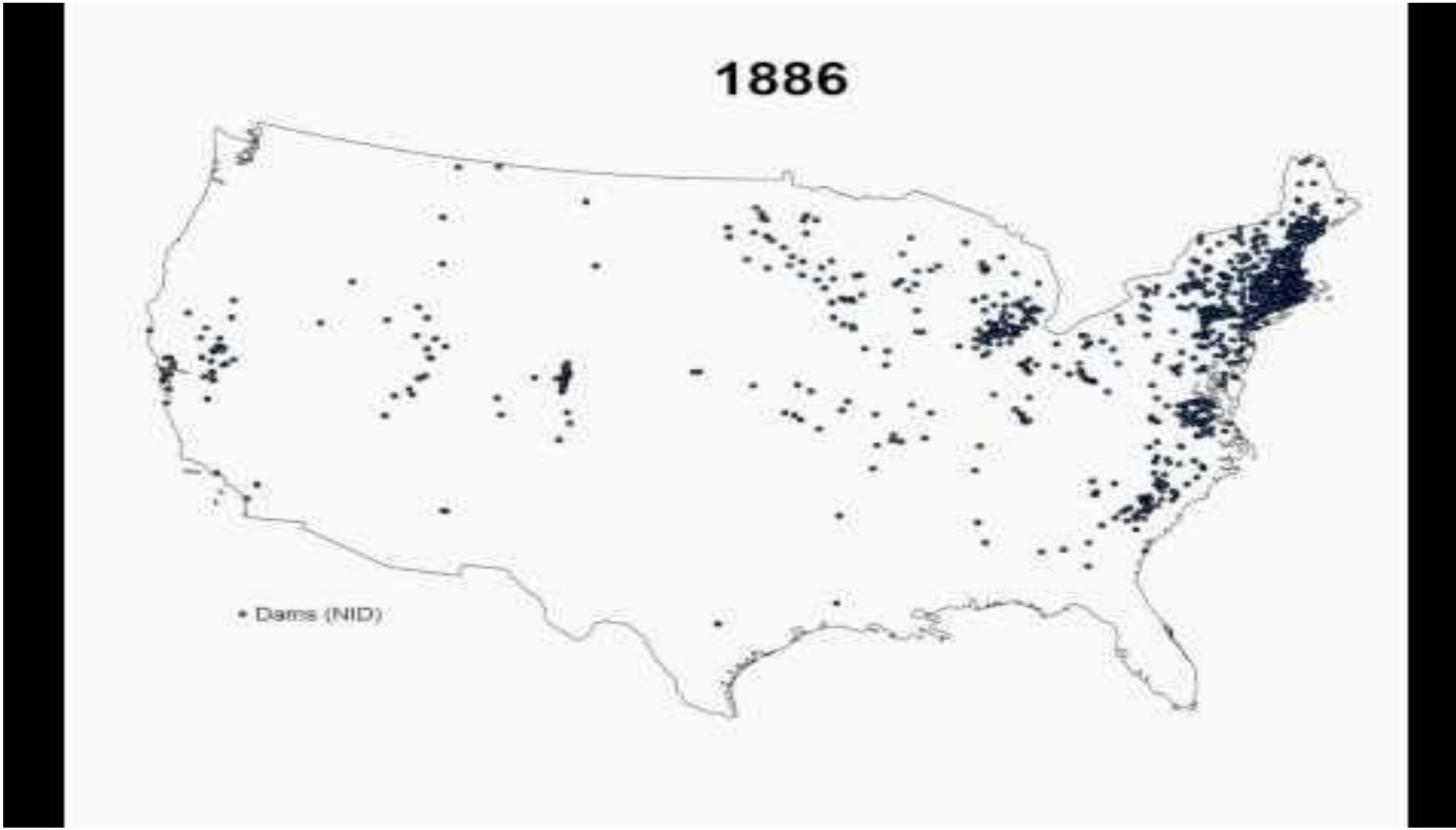




CR > GPP ??

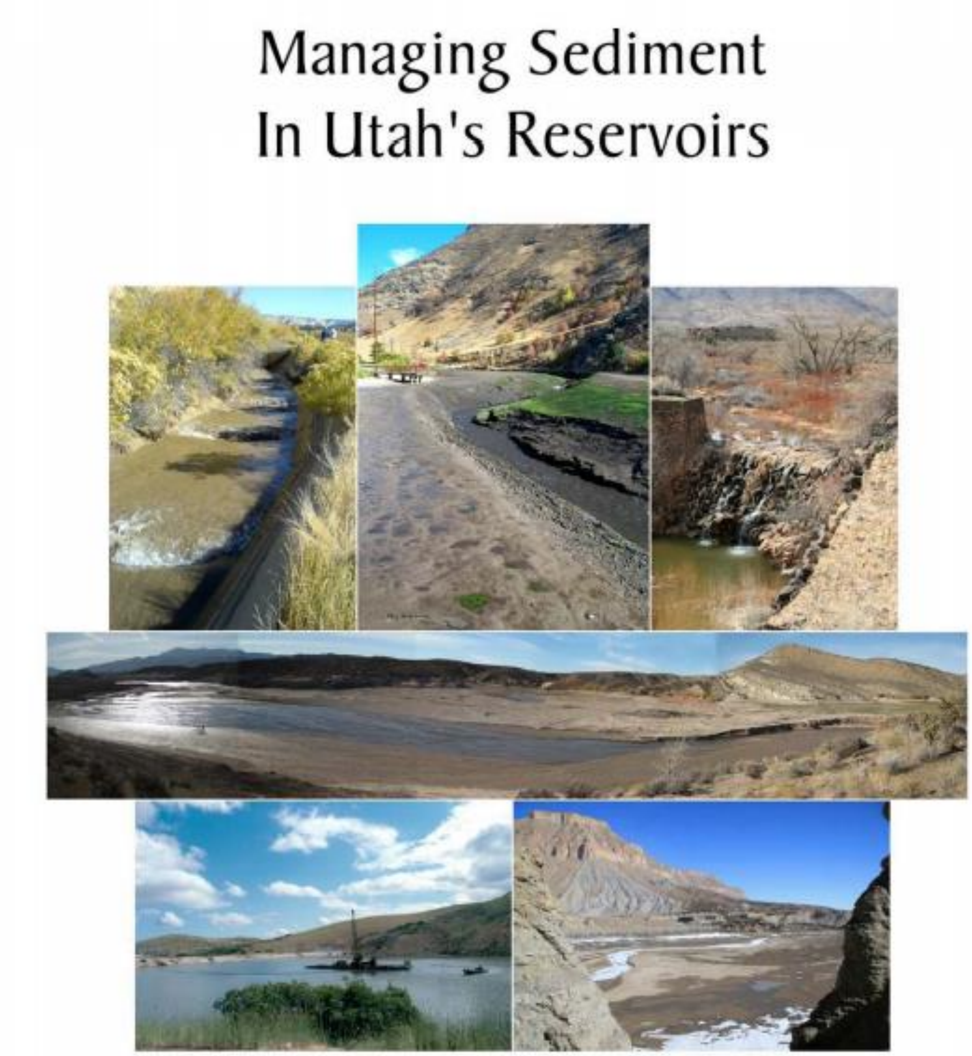
Hypoxia follows when
Gross primary production < community respiration

Lakes and Reservoirs: Understanding Processes and Interplay



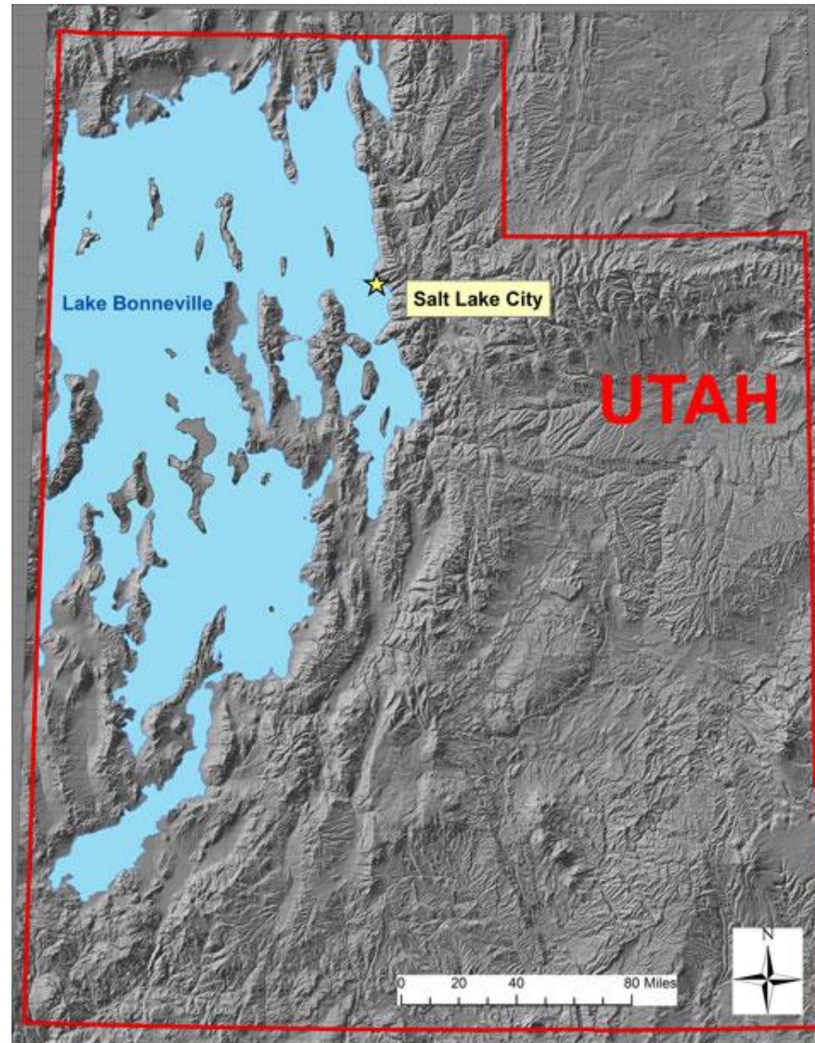
Lakes and Reservoirs: Understanding Processes and Interplay

- **“Humans have simultaneously increased the sediment transport by global rivers through soil erosion (by 2.3 billion Mg/yr), yet reduced the flux of sediment reaching the world’s coasts (by 1.4 billion Mg/yr) because of retention within reservoirs.” ~Syvitski et al., 2007**
- **Eutrophication and anoxia common in reservoirs, while anoxia can also potentially lead to nitrogen limitation downstream**



A brief history of Utah Lake and its watershed

- **Formed ~10,000 years old, remaining from Lake Bonneville**
- **European occupation in 1849**
- **"The outlet of Utah Lake does not form a large river neither a rapid current but the water is muddy and low banks.“ – Clayton, 1847 (via Bushman 1980)**
- **“This is a beautiful sheet of pure fresh water, thirty miles in length, and about ten in breadth” – Stansbury, 1852 (via Bushman 1980)**
- **Controlled for water supply (increased surface elevation and flux) since 1872**
- **Carp introduced in 1880s**
- **Dust bowl in the 1930s**



https://wildlife.utah.gov/gsl/history/bonneville.jpg

A brief history of Utah Lake and its watershed

- **"Utah Lake today is astonishingly free from aquatic vegetation yet it is within the memory of many when various species of *Potamogeton* and similar forms made rowing almost impossible along the shores and in the protected parts of the lake." – Cottam, 1926 (in Bushman 1980)**
- **"We have found that the diatom flora dominating the lake today is very similar to that which existed as long as 11,000 years ago. It is therefore possible that man has had a minimal effect on Utah Lake, contrary to what many have previously believed." – Hanson et al., 1974 (in Bushman 1980)**

https://archive.sltrib.com/images/2012/0713/lookback_rec_071312~1.jpg

http://utahlakecommission.org/wp-content/uploads/2014/07/canal-blasting.png

Understanding in-lake sediments and their relationship with current and future lake depth and water quality

- ***As a lake becomes shallower…***
  - Sedimentation rates may increase (higher CA:LA ratio, greater volumetric phytoplankton production) or possibly decrease (greater interception by wetlands, diminished water column depth)
- **Ultimately depends on catchment characteristics, shoreline biota, and lake bathymetry**

http://epod.typepad.com/.a/6a0105371bb32c970b0115710f74fb970c-pi

Understanding in-lake sediments and their relationship with current and future lake depth and water quality

- ***As a lake becomes shallower…***
  - Sediment burial efficiency (burial rate / deposition rate) may increase (macrophytes stabilizing sediments and depositing more recalcitrant organic carbon than algae) or decrease (bacterial mineralization of organic carbon is more effective in well-oxygenated environments).
- **Depends on presence of macrophytes, benthic primary production, and mixing**

https://www.havet.nu/images/870/6528.jpg

Understanding in-lake sediments and their relationship with current and future lake depth and water quality

http://utahlakecommission.org/wp-content/uploads/2014/07/memorial.png

- **Lake depth: controlled by water levels (short time span), but future levels will be a balance between sediment supply (either autochthonous or allochthonous) and sediment loss (typically by mineralization).**
- **Brimhall (1972) calculated a 75 year lifespan of the lake given contemporary sedimentation rates (mostly calcite)**

Understanding in-lake sediments and their relationship with current and future lake depth and water quality

http://mediad.publicbroadcasting.net/p/kuer/files/styles/medium/public/201707/2017-06-27-Utah-Lake-ESA.jpg

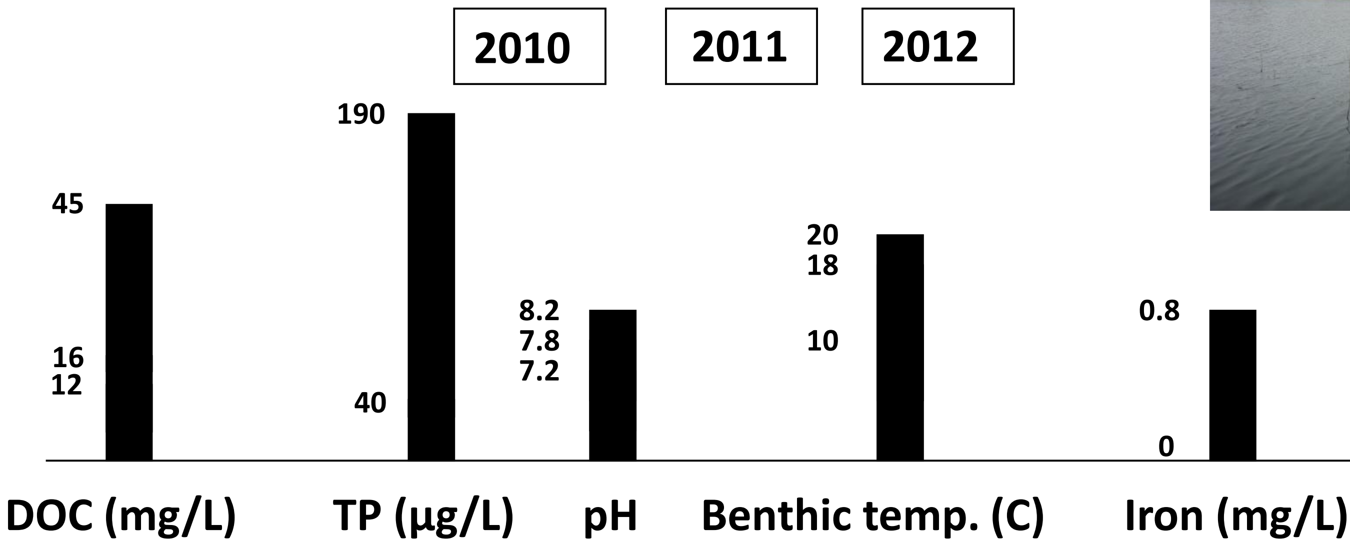
- **Current ecosystem does not stabilize the sediments (active bioturbation by carp, lack of macrophytes to stabilize against wind-driven mixing), meaning that more nutrients are consistently made available to phytoplankton and cyanobacterial blooms.**
- **Potential for internal chemical loading? If it occurs, it would be expected in wind-sheltered bays where sediment-water anoxia could develop more readily**

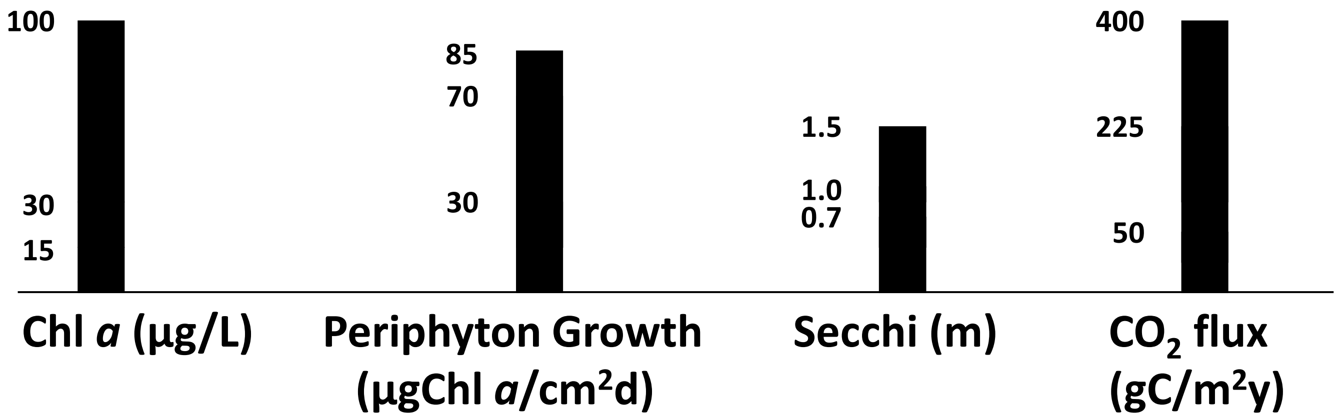
How Utah Lake may have changed due to the regulation of the outflow to the Jordan River

- **Higher lake levels can increase turbidity and contribute to anoxia**
- **More regulated outflows may diminish sediment transport out of the lake**

https://www.utahcleanwater.org/uploads/4/7/2/2/47227279/7307064.jpg?447

What one year of flooding did to a shallow lake in Germany





Initial thoughts on key questions the ULWQS effort might want to consider

- **What is the specific historical timeline of this lake's water quality (macrophyte presence, chironomid community, etc.)?**
- **What is the role of the benthic zone vs. water column (or watershed) in producing algal blooms and current water quality issues?**
- **What is the best approach (and feasible timeline) for addressing internal nutrient loading in remediation efforts? *"Stable clear-water conditions and a diverse macrophyte flora only [occurs] decades after external nutrient load reduction or when [internal and external] measures [are] combined."* – Hilt et al., 2018**
- **Are the net effects of Phragmites removal efforts beneficial to the lake?**